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MEASURED AIRBLAST ENVIRONMENT FROM AN EXPLOSIVE CHARGE HAVING A SCORED METAL CASING

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For most applications, the introduction of a metallic casing tends to reduce the intensity of the airblast from the cased charge. Most predictive methods assume that the inertial resistance of the casing is the dominant parameter in estimating the reductions in peak airblast pressure and impulse. This enables the use of simple formulae to estimate bare charge equivalents for cased charges which consider only the relative masses of explosive and casing material. Recent experiments have shown that casing material properties can significantly influence the resulting airblast field from a cased explosive charge, suggesting that in certain cases, other parameters besides the relative masses of casing material and explosive might be required. To further pursue these findings, a special cased explosive charge was designed and tested on the AFRL blastpad.

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MEASURED AIRBLAST ENVIRONMENT FROM AN EXPLOSIVE CHARGE HAVING A SCORED METAL CASING

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ABSTRACT

For most applications, the introduction of a metallic casing tends to reduce the intensity of the airblast from the cased charge. Most predictive methods assume that the inertial resistance of the casing is the dominant parameter in estimating the reductions in peak airblast pressure and impulse. This enables the use of simple formulae to estimate bare charge equivalents for cased charges which consider only the relative masses of explosive and casing material. Recent experiments have shown that casing material properties can significantly influence the resulting airblast field from a cased explosive charge, suggesting that in certain cases, other parameters besides the relative masses of casing material and explosive might be required.

To further pursue these findings, a special cased explosive charge was designed and tested on the AFRL blastpad. This casing was "scored" with a carefully designed pattern of grooves. Within a scored groove, the casing thickness was the same as lightly-cased charges tested previously on the blastpad. Between the grooves, the casing thickness was very nearly the same as medium-cased charges tested previously on the blastpad. Overall ratios of casing mass to explosive mass were the same as the medium-cased charge. The measured airblast field from the charge with the scored casing was then compared to those from previous blastpad tests. Given this scheme of experimentation, agreement of the airblast field from the scored-cased charge with that of the medium-cased charges would imply that the inertial resistance of the casing was the dominant parameter influencing the airblast field. Conversely, better agreement with the airblast fields from the lightly-cased charges would imply that characteristics of casing fracture were dominant. In this paper, the experiment with the scored-cased charge is described, and airblast fields compared to gain proper insight into the underlying physical behaviors affecting airblast production from cased charges.

INTRODUCTION AND BACKGROUND

Because of the limited experimental data available from cased explosive charges, the airblast environments from this class of explosive charge are not as well understood as bare explosive charges. Nearly all of the predictive methods known to the authors are different variations on modifying the yield of the explosive charge in an attempt to account for the casing effect. Since the casing must be expanded, fractured, and then accelerated to typical fragment velocities, it is logical that a considerable amount of energy must be associated with these processes. This energy would be unavailable for airblast production, and thus these predictive

methods all reduce the yield (or explosive mass) of the cased charge to account for the presence of the casing. Analysts will then compute the airblast environment from this reduced-yield charge as if it were a bare sphere or bare cylinder of some explosive type (usually TNT). Numerous formulae exist to aid the analyst in determining the bare charge equivalent mass with which to represent the cased charge. These formulae only include the case mass-to-explosive mass ratio and the actual explosive mass of the cased charge as parameters. Hence, the case mass-to-explosive mass ratio, a measure of how heavily the explosive fill is cased, tends to dominate the determination of the bare equivalent charge.

Questions have been raised regarding the accuracy of these formulae, and their appropriateness for predicting the airblast from modern cased charges. When considering the cylindrical shape of the cased charge, the use of non-ideal explosive fills, and the use of different casing materials, it is not clear that a case-reduced, spherical, bare charge will adequately represent the airblast environment from such a complicated explosive device. This concerned was affirmed through a program of novel experiments described in the 18th MABS [1]. A special sub-scale cased charge was devised with a "composite" casing produced from tungsten and nickel powder suspended in an epoxy matrix. The resulting casing had the same density as steel, and thus had the same mass ratios as previously tested charges constructed from 4340 steel casings. However, the tungsten-nickel-epoxy (W/Ni/Epoxy) casing had dramatically less mechanical strength and ductility than its steel counterpart. Each type of casing was tested on the Air Force Research Laboratory (AFRL) blastpad, providing a detailed characterization of the airblast field for each. Upon comparison of the measured peak pressure and peak impulse fields, substantial increases in peak pressure and peak impulse were observed from the W/Ni/Epoxy-cased charge. Thus, even though the case mass-to-explosive mass ratios were identical, imposing a dramatic change in casing material properties produced a significant change in the resulting airblast environment. A clear conclusion from the experiment series was that dramatic changes in casing material properties can defy the classic assumption of airblast from cased charges being dominated by the inertial resistance of the casing.

It was desired to augment this experimental finding by conducting yet another experiment with a unique casing configuration. Admittedly, the W/Ni/Epoxy casing was a novel casing design utilizing materials and material properties far removed from conventional metals often employed with cased charges. It was decided to further investigate the casing effects on airblast through careful design and fabrication of a "scored" steel casing. This scored casing would have a regular pattern of grooves machined into the outer surface of the casing. The case mass-to-explosive mass ratio was identical to that of "medium-cased pentolite charges" previously tested on the AFRL blastpad. If the inertial resistance of the casing tended to dominate the production of airblast from the scored casing, the measured airblast fields would be expected to be similar to the medium-cased pentolite charges. The depth of the grooves however, was machined to a depth that resulted in a casing thickness identical to that of the "lightly-cased pentolite charge". If the failure of the casing along the preferential pattern of the scoring dominated the release of airblast from the cased charge, the measured airblast fields would be expected to better match those of the previously tested lightly-cased pentolite charges. In this way, additional insight would be gained toward the physical mechanisms of greatest importance in predicting the airblast from a cased charge.

This study was conducted as part of a continuing program of experimentation utilizing the AFRL blastpad for characterizing the airblast fields from cased explosive charges. The ability

of the instrumented blastpad to measure detailed airblast environments from cased charges without suffering fragment strikes made it particularly useful for this investigation. Readers may find it helpful to reference previous blastpad papers published in the MABS, including a paper in the 17th MABS described the AFRL blastpad and its use for quantifying asymmetric airblast environments surrounding cased charges [2], blastpad tests of the W/NI/Epoxy-cased charges in the 18th MABS [1], and blastpad tests comparing airblast from cased cylinders and corresponding generic penetrators in the 18th MABS [3]. This paper describes the blastpad experiment of the scored steel casing, compares the measured airblast fields to previously measured airblast fields of medium and light casing weight, and summarizes the primary findings from the investigation.

DESCRIPTION OF THE EXPERIMENTS

Overview Of The Instrumented Blastpad Experimental Method

A brief description of the instrumented blastpad concept is provided here for the sake of completeness. Figure 1 is an isometric sketch of the instrumented blastpad as viewed from above. The blastpad is a roughly 42.7-m long by 24.4-m wide concrete slab that contains 70 surface flush instrumentation mounts arranged concentrically around a replaceable detonation area. The replaceable detonation area consists of a steel-lined rectangular box (1.4-m long by

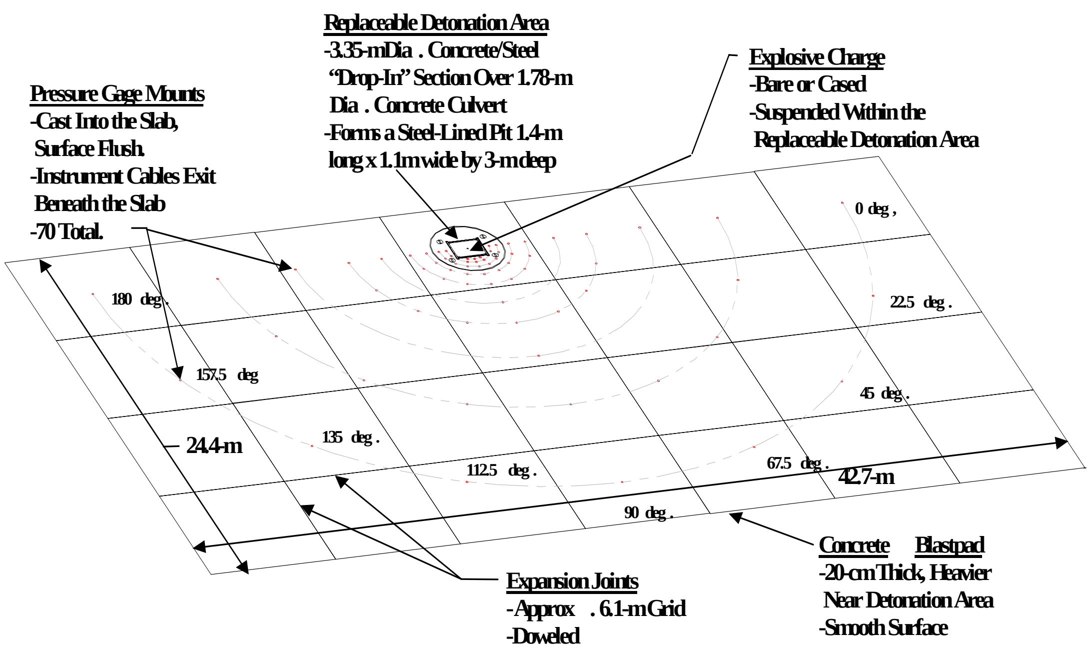

Figure 1. Isometric view of the AFRL instrumented blastpad.

1.1-m wide x 0.61-m thick) positioned over a 1.78-m diameter, 2.44-m deep steel-lined pit (resulting in a total depth of 3.05-m). Instrument cables are routed through conduits beneath the pit to a junction box some distance away.

To conduct a typical experiment, the candidate explosive charge is suspended within the replaceable detonation area (referred to hereafter as the blast pit) so that half of the explosive

charge is above the plane of the blastpad surface, and half of the explosive charge is within the blast pit. Stated differently, the equator of the explosive charge is contained within the plane of the blastpad surface. This is shown conceptually in Figure 2 with a cased explosive charge. Upon detonation, the cased explosive charge expands naturally within the void space of the blast pit until the case breaks into its fragments. Blast and fragments from the upper half of the explosive charge propagate over the surface of the instrumented blastpad where the surface flush blast pressure gages measure the incident pressure from the cased explosive charge. Since the instrumentation is mounted surface flush, the measurements are not vulnerable to fragment impacts. Blast and fragments from the lower half of the explosive charge propagate into the blast pit below. Fragments strike the steel lining of the blast pit and the concrete floor, causing some damage. The steel linings are replaceable, so that the extensively damaged portions can be replaced after several experiments. Blast from the lower half of the explosive charge will propagate to the bottom of the 3.05-m deep pit and reflect back up and out of the replaceable detonation area. This reflected blast is then free to diffract back over the surface of the blastpad where it would be recorded by the surface flush blast pressure gages. The delay in time of this reflected blast is sufficient however, to fully characterize the initial direct blast from the cased explosive charge. In this way, experiments can be conducted to quantify the blast fields from cased explosive charges.

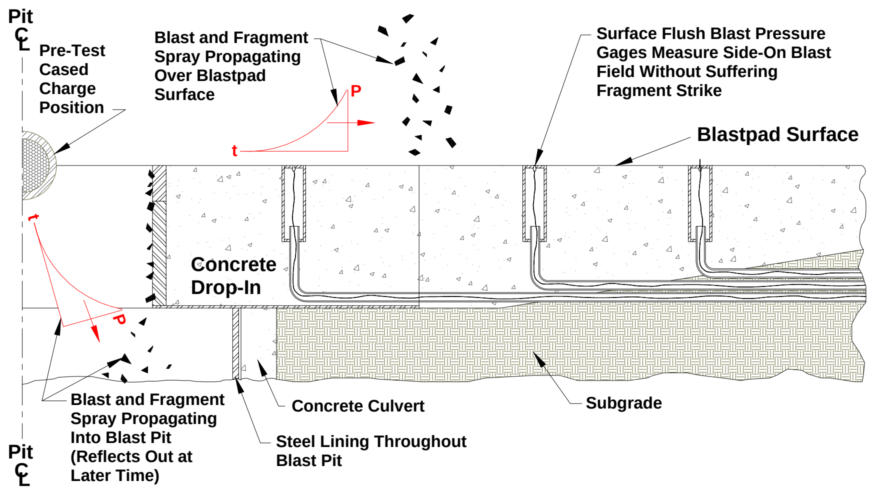

Figure 2. Cross-sectional view of the instrumented blastpad detonation area, illustrating the testing concept.

<u>Baseline Medium and Light-Cased Pentolite Charges</u>

It was desired to design a scored steel casing that would correspond to the previously tested medium-cased pentolite charge in terms of overall case mass-to-explosive mass ratio, yet would correspond to the previously tested lightly-cased pentolite charge in terms of case thickness remaining at the scorings. These “baseline” charges influenced the physical design of the scored casing, and the measured airblast fields from the baseline charges served as the basis for which the measure airblast from the scored casing was compared. Hence, a detailed description of these baseline charges ensues.

Cross-sections of the medium-cased and lightly-cased pentolite charges are shown in Figure 3. The explosive fill for each cased charge was identical, having a mass of 3.88-kg, a diameter of 82.2-mm, and a length of about 446-mm. 4340 steel, with a modest heat treatment, was the casing material for all of the charges. Case mass-to-explosive mass ratio was deliberately changed for these two cased charge designs, with the medium-cased charge having a total case mass-to-explosive mass ratio of 2.55 and the lightly-cased charge have a total case mass-to-explosive mass ratio of 1.06. These mass ratios correspond roughly to notional thick-cased munitions associated with penetrators, and notional thin-cased munitions associated with general purpose bombs, respectively. End conditions at the "nose" of the cased charge were simulated by welding a flat plate of appropriate mass, and similarly, the "tail" condition was simulated with a threaded flat plate of appropriate mass. In general, care was taken to distribute the mass of the casing in a reasonable manner. Each cased charge was initiated at its "tail" using a 25-mm diameter by 25-mm tall Composition A5 booster with an electronic detonator, positioned as shown in Figure 3.

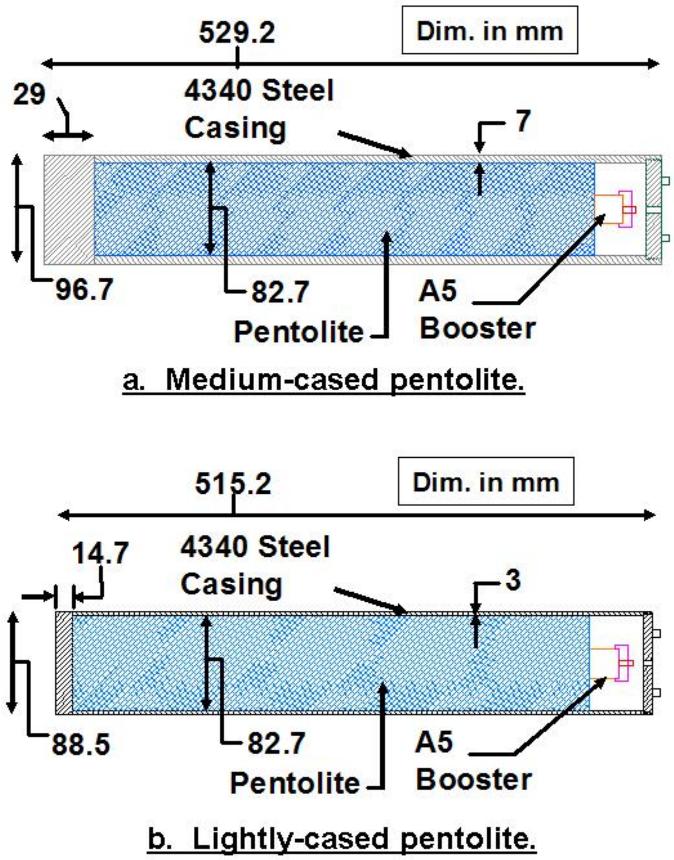

Figure 3. Cross section of medium-cased and lightly-cased pentolite charges.

Design of the Scored Casing Test Item

In the design of the scored casing, several parameters were deliberately held constant relative to the medium and lightly-cased pentolite charges. First, the pentolite explosive fill was identical to that of the previously tested charges in mass, physical dimension, and method of initiation. Secondly, the inner diameter and length of the casing interior cavity were the same as that of the previously tested charges. To achieve the design objectives for case mass-to-explosive mass ratio and casing thickness, a pattern of scoring was machined into the casing wall and nose. This groove pattern is evident from the cross-section of Figure 4. Comparison of the scored casing in Figure 4 to its un-scored counterparts in Figure 3 shows that the casing thickness at the position of the groove is approximately 3-mm, identical to that of the lightly-cased pentolite charge. Scoring of this groove depth was applied in a 12.6-mm square pattern over the cylindrical surfaces of the cased charge. Removal of the steel within the groove pattern reduced the mass of the cylindrical portion of the cased charge, reducing its case mass-to-explosive mass ratio. To keep the case mass-to-explosive mass ratio the same as the medium-cased pentolite charge, thickness was added to the square segments between the grooves. Hence, at positions between the grooves, the scored casing is slightly thicker than that of the medium-cased pentolite charge, but the case mass-to-explosive mass ratio is the

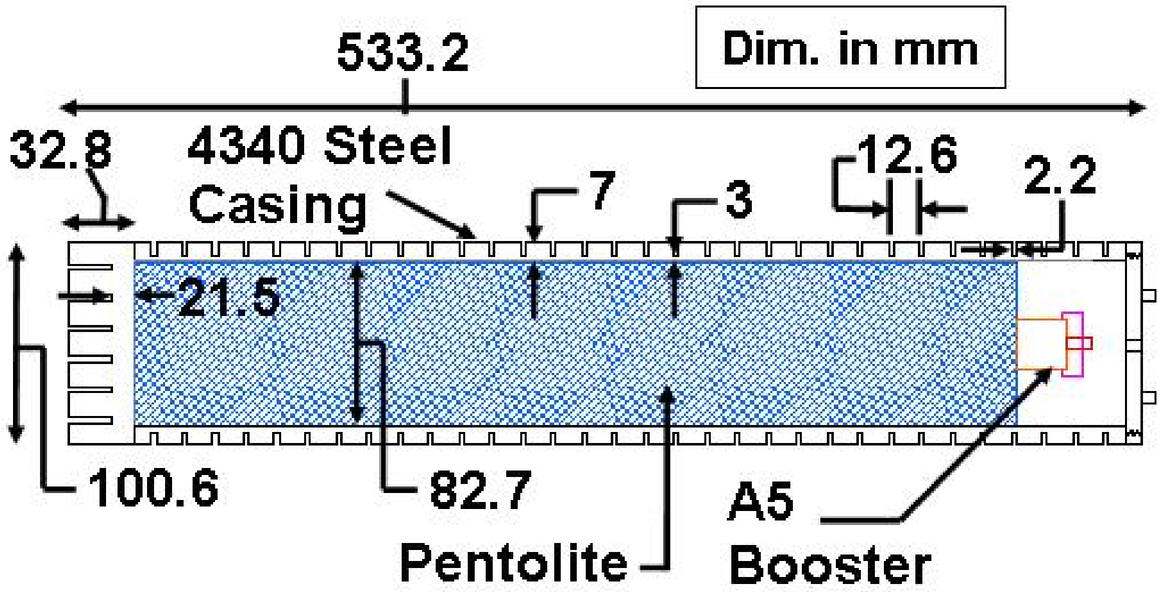

Figure 4. Cross section of the explosive charge with the scored casing.

same. A similar scoring approach was applied to the nose plate of the scored casing, with the thickness at the grooves similar to the nose thickness of the lightly-cased pentolite charge, and the thickness between the grooves somewhat larger than its medium-cased counterpart to arrive at proper mass of the nose plate. A photograph of the scored casing is given in Figure 5.

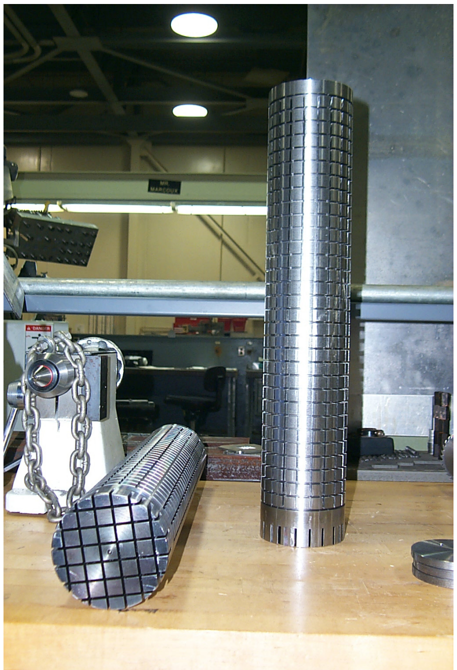

Figure 5. Photograph of two scored casings prior to insertion of explosive fill.

<u>Experiment Description for the Scored Casing</u>

To conduct the blastpad experiment, the scored casing explosive charge was carefully positioned within the rectangular opening above the blast pit, with the explosive center of gravity located precisely at the center of the blastpad instrument plane (i.e., x=0, y=0, z=0). This was facilitated by placing the cased charge upon a styrofoam block supported on a wooden rack, simulating a suspended condition. This is shown in the photograph of Figure 6 for the scored casing explosive charge (Blastpad Test #73). Figure 7 provides a plan view of a typical blastpad experiment, indicating the positions of pressure transducers and orientation of the end-detonated cased cylinder. Thirty-eight pressure transducers were fielded in the positions indicated by the blue markers in Figure 7, in contrast to thirty-two blast pressure transducers fielded on some earlier blastpad experiments. These were piezo-resistive pressure transducers utilizing down-range signal conditioning and digital recording. For the sake of consistency, the detonation end of the cased charge (i.e., the "tail" for most air-delivered munitions) is oriented toward the 0-degree azimuth and the "nose" toward the 180-degree azimuth.

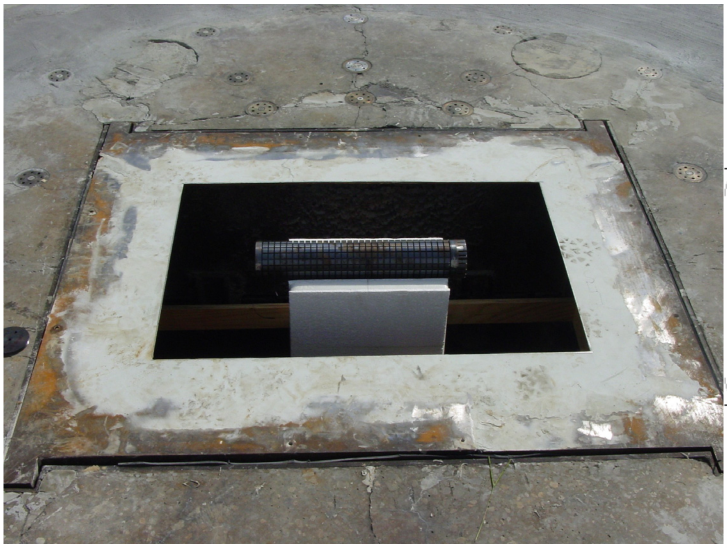

Figure 6. Pretest photograph of the scored casing charge in place for Test #73.

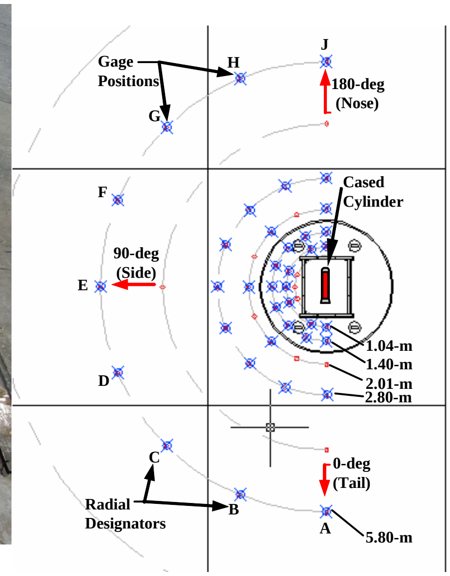

Figure 7. Plan view of blastpad test layout (pressure gages).

An additional feature was added to the scored casing blastpad experiment. Fragment collection bundles were placed approximately 4-m away from the scored casing on the un-instrumented side of the blastpad. By positioning the fragment bundles at this distance, fragments were expected to propagate ahead of the airblast, and undesired reflections from the collection bundles would not interfere with the primary airblast pressure measurements. Three separate fragment collection bundles were fielded, each 1.32-m thick with a break screen applied to its front surface. Thus, a measure of fragment velocity and mass distribution would be obtained from each bundle. Figure 8 shows the fragment bundles positioned relative to the scored casing explosive charge.

Figure 8. Pretest photograph of the scored casing charge and fragment collection bundles.

COMPARISON OF MEASURED WAVEFORMS

Full duration airblast pressure waveforms were obtained at nearly all of the thirty-eight instrumented positions on the scored casing blastpad experiment (Test #73). These measurements were then compared to corresponding measurements from the lightly-cased pentolite charges (Tests #23, #33, and #38) and the medium-cased pentolite charges (Tests #24, 30, and #34). One manner of comparing the measured airblast environments was to compare measured waveforms at points of interest. An example of such a comparison is exhibited in Figure 9 for the measurement radial directly off of the side of the cylindrically-shaped charges (the "E"-radial). Red traces on the graphs of Figure 9 are measurements from the scored casing. Similarly, the green traces are from the lightly-cased charges (Test #38) and the blue traces from the medium-cased charges (Test #34). The graphs are arranged in the order of increasing distance from the charge in Figure 9, and accordingly, pressure levels can be observed to decrease with distance from the explosive charge, and pulse durations increase with distance. Small shocks preceding the primary airblast wave can be observed at the 2.8-m and 5.8-m measurement positions. Experience has shown these small shocks to be "bow" shocks associated with supersonic flight of nearby fragments, indicating ranges where fragment propagation precedes the airblast propagation.

Subtle trends are observable from studying the individual waveform comparisons. The highest peak pressures are always associated with the lightly-cased charge. In most instances, the scored casing produces the next highest peak pressures followed by the medium-casing. Airblast time-of-arrivals are always earliest (i.e., fastest shock speed) for either the lightly-cased or scored charge. Impulse trends from the entire data set are best represented by the graphs for the 2-m and 5.8-m ranges. These graphs illustrate the tendency for the impulse from the lightly-cased charge to be significantly higher than that of the medium-cased charge, with the impulse from the scored casing falling in between. In general, the very close-in charges at the 1.04-m 1.4-m ranges typically displayed considerable scatter, especially at measurement positions within the fragment beam spray.

Airblast parameters of interest, namely time-of-shock-arrival, peak pressure and peak impulse, were selected from all of the measured waveforms. Annotations on Figure 9 indicate the typical interpretations of these parameters.

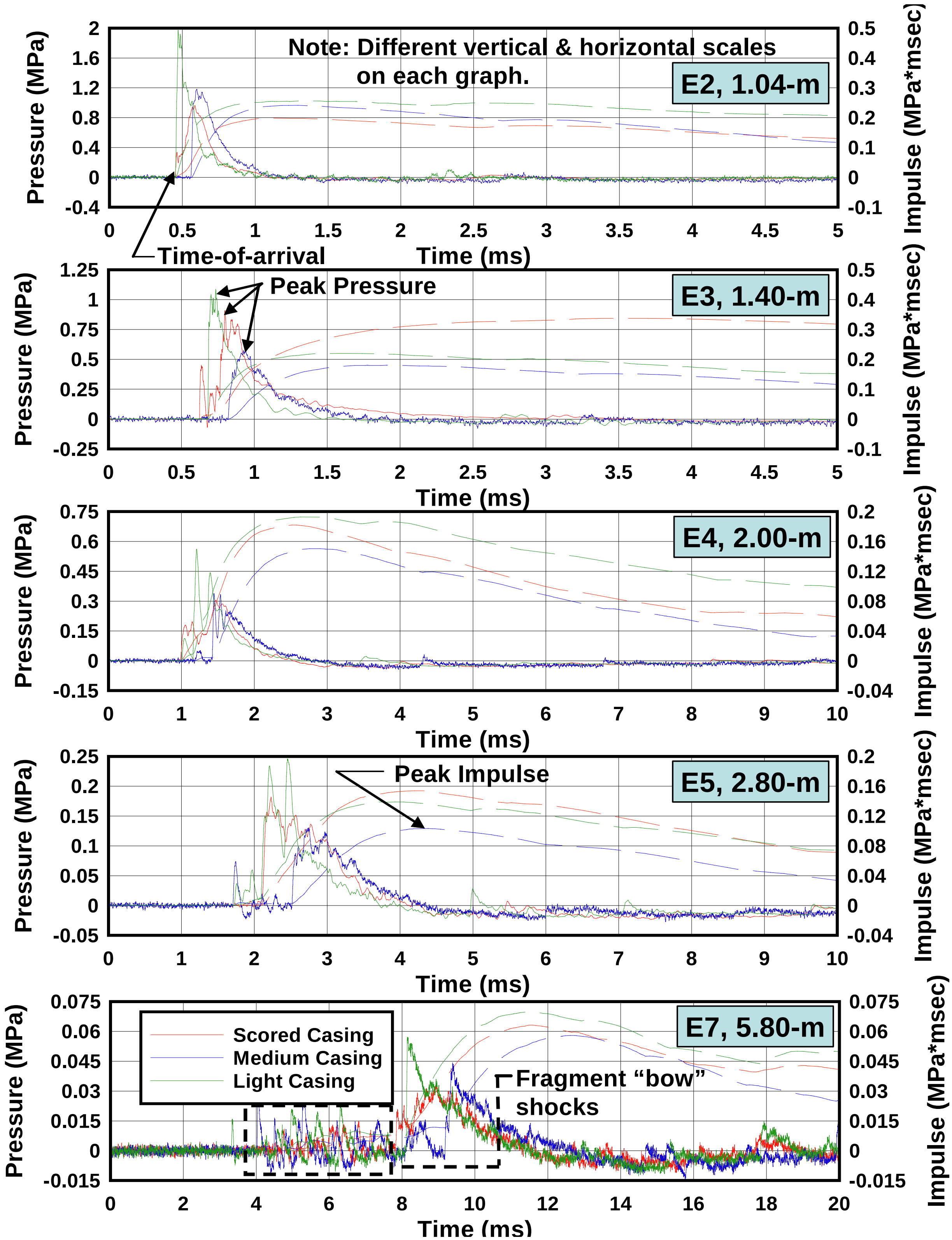

Figure 9. Measured airblast pressure waveforms off of the side of the scored casing charge, lightly-cased charge, and the medium-cased charge.

COMPARISON OF THE MEASURED AIRBLAST FIELDS

Given the relatively large number of airblast pressure measurements from a blastpad experiment, it is possible to generate fields of an airblast parameter of interest. This often exhibits free-field airblast characteristics more clearly than inspection of discrete waveforms. This can be especially valuable in light of the measurement scatter that occurs within a typical airblast experiment, and the scatter that occurs amongst data collected from replicate experiments. Accordingly, airblast parameter fields were produced for the scored casing experiment, and for the lightly-cased and medium-cased explosive charges.

Peak pressures, shock time-of-arrivals, and peak impulses were compiled for all thirty-eight of the airblast measurements from the scored casing experiment. Similarly, corresponding airblast parameters were compiled for each of the replicate experiments of the lightly-cased and medium-cased charges. Since more than one data set existed for the lightly-cased and medium-cased charges, parameters from these data sets were averaged to produce a single tabulation of airblast parameters for each type of charge. Thus, the scored casing parameter fields would be compared against the average parameter fields from the lightly-cased and medium-cased charges. Shock time-of-arrival, peak pressure, and peak impulse contours were then generated from each type of cased charge. In order to consistently generate the parameter fields, two details are noteworthy. First, imaginary data points were introduced for the extreme near-field of the contours, and these points were introduced consistently for each charge type. This assured reasonable scales and contours for the instrumented portion of the measurement domain, and provided a consistent manner of producing contours where instrumentation could not be successfully fielded. Secondly, the experiments for the lightly-cased and medium-cased charges were conducted in the 2003 timeframe with thirty-two airblast pressure gages instead of thirty-eight. With this earlier instrument array, only three gages were placed at the 5.8-m range. The sparsity of gages at the outermost range caused difficulty in the creation of contour plots. In order to fully populate the 5.8-m range, additional points were imposed using interpolation from the three measured airblast pressures.

Contour plots of shock-time-of-arrival are displayed for all three cased charges in Figure 10. Casual inspection of the plots shows a great deal of similarity in the time-of-arrival contours, although, it should be realized that very subtle difference in shock arrival times can imply a substantial difference in airblast performance. Careful inspection shows the time-of-arrival contour of the scored casing to be quite similar to the lightly-cased charge off of the side of the position, and slightly slower off of the “nose”. Shock arrivals are noticeably slower for the medium-cased charge off of the side and nose, while differences are more subtle off of the tail. In general, it can be observed that the time-of-arrival contour for the scored casing lies between the light and medium-cased charges. Also, the contour from the scored casing exhibits different shape in the very near-field, implying a more rapid shock travel off of the nose of the cased charge. This effect is less noticeable with increasing range.

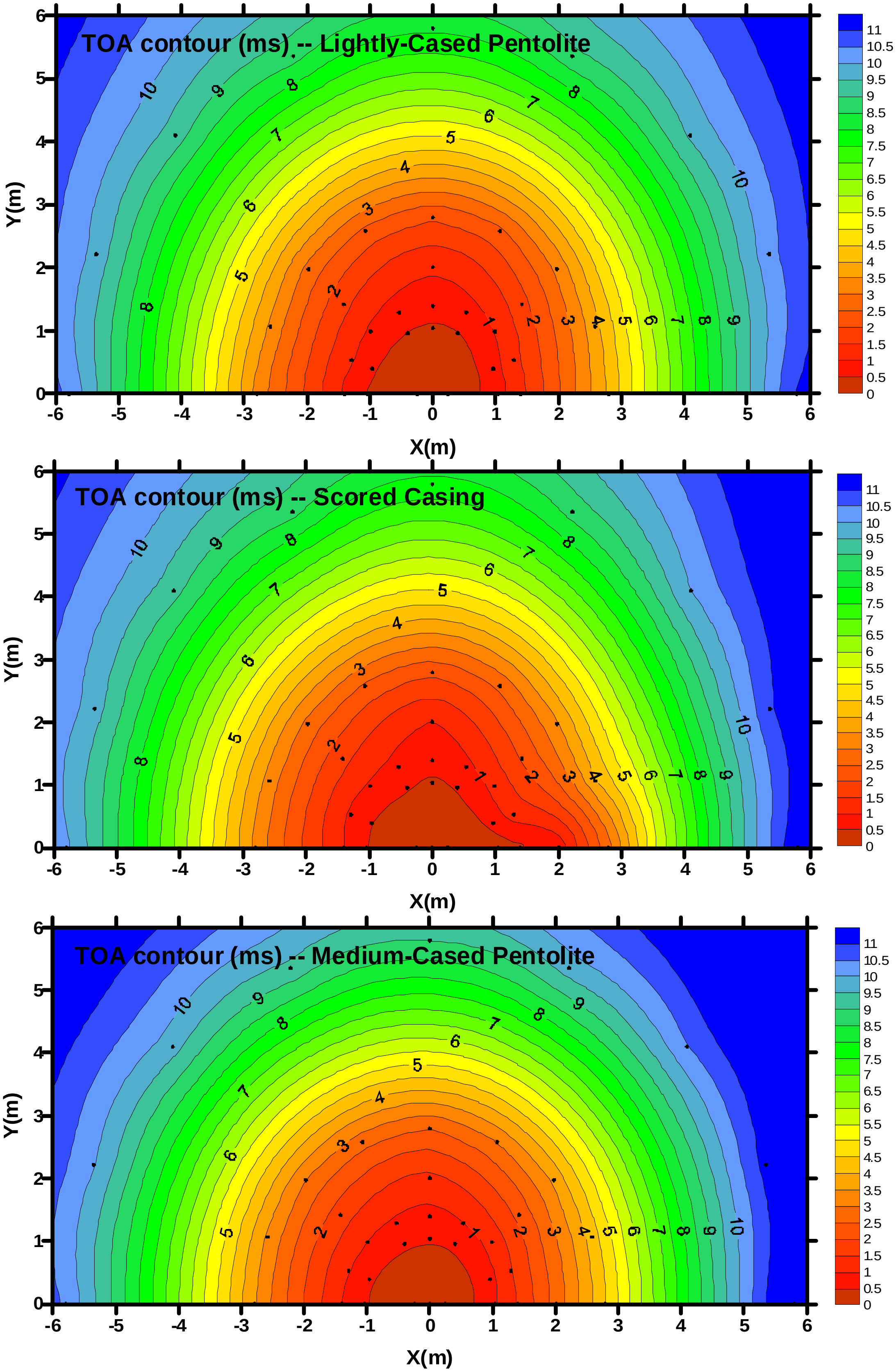

Figure 10. Shock time-of-arrival contours for the scored casing charge, lightly-cased charge, and medium-cased charge.

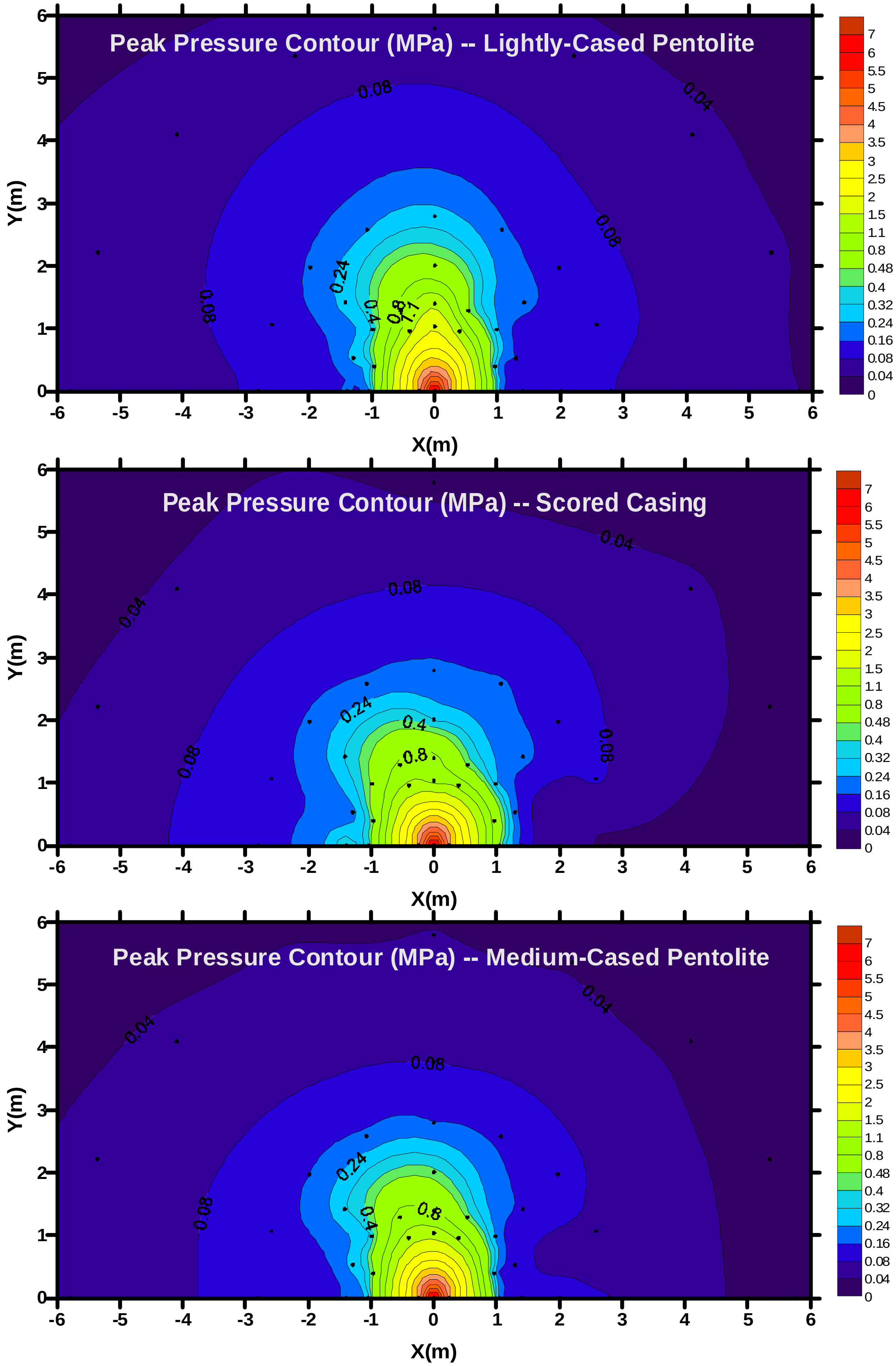

Figure 11. Peak pressure contours for the scored casing charge, lightly-cased charge, and medium-cased charge.

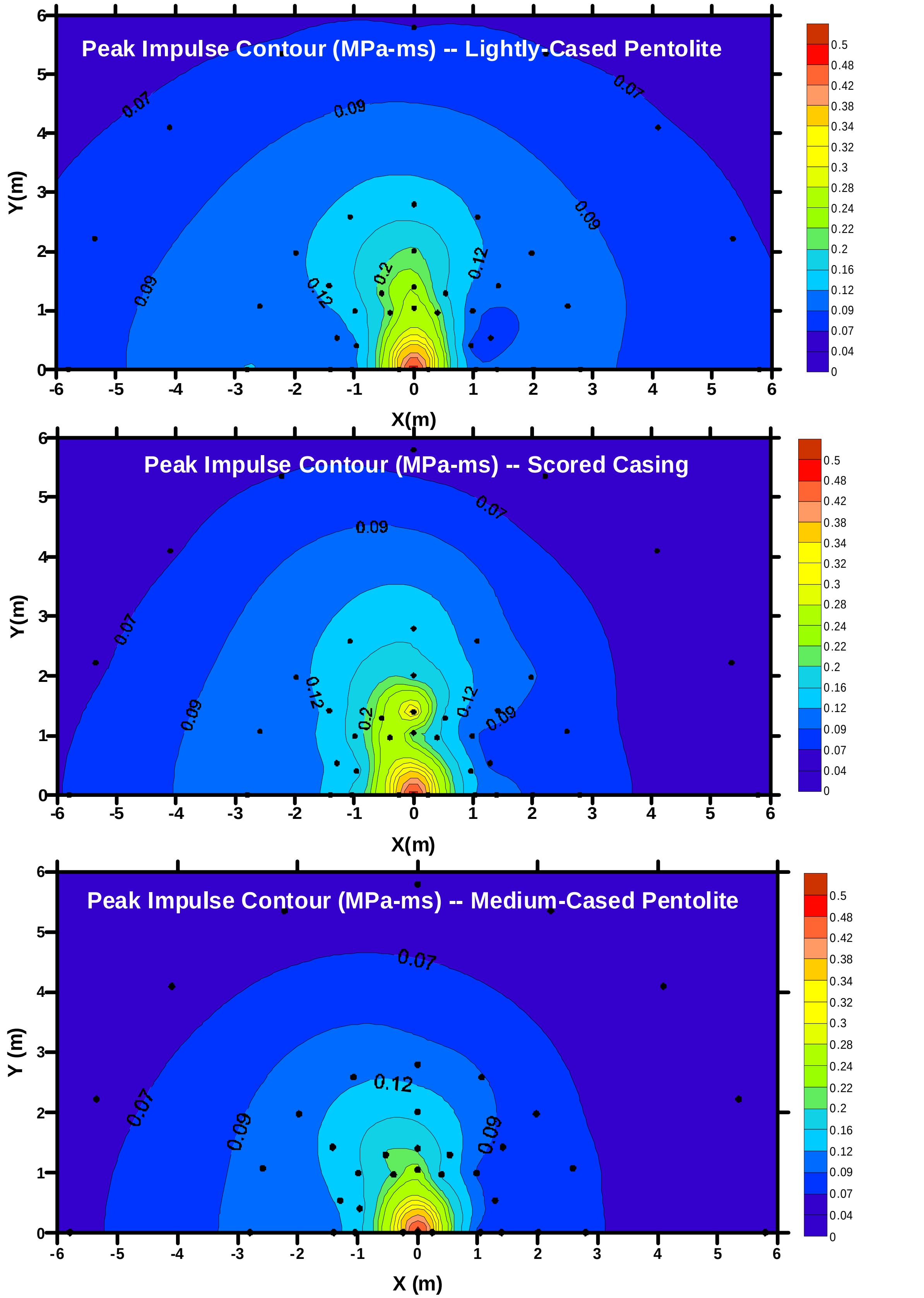

Figure 12. Peak impulse contours for the scored casing charge, lightly-cased charge, and medium-cased charge.

Figure 11 shows the contour plots for peak pressure in a similar fashion. It can be readily observed that the lightly-cased charge produces consistently higher peak pressures at comparable measurement ranges. Upon careful inspection, the peak pressure contour is very similar to that of the medium-cased charge, with some subtle improvements in peak pressure performance in portions of the airblast field (i.e., compare the 0.08-MPa contours, etc.).

Finally, peak impulse contours are displayed in Figure 12, with two noteworthy observations. First, a casual inspection of the peak impulse contours places the impulse performance of the scored casing between that of the lightly-cased and medium-cased charges. This is most readily observed by noting the positions of the outermost contours of the three charge types. Secondly, the scored casing tends to direct more airblast to the side of the cased charge. It can be noted that the contours of the scored casing look more like those of the lightly-cased charge off of the side (i.e., 90-deg. azimuth). Conversely, the contours from the scored casing look more like those of the medium-cased charge off of the tail and nose of the charge (i.e., the 0-deg. and 180-deg. azimuths).

It is clear that the scoring had an effect on the resulting airblast field. If the scoring had no effect, the resulting airblast fields would have been identical, or at least very similar, to those of the medium-cased charge. While this was true off of the ends of the charge, the airblast environment off of the side of the cased charge was more similar to that of the lightly-cased charge. This observation supports the school of thought that casing expansion and fracture characteristics are of most importance for predicting airblast from cased charges. Conversely however, peak pressure environments from the scored casing charge were more similar to the medium-cased charge, as well as the impulse environments off of the ends. This observation supports the school of thought that the inertial resistance of the casing (i.e., its mass relative to the explosive mass) is of most importance for predicting airblast from cased charges. Given the "intermediate" airblast performance from the scored casing charge, it is the opinion of the authors that the test results indicate that both inertial resistance of a casing, as well as its geometric expansion and ductility properties, are necessary for high quality prediction of resultant airblast environments.

CONCLUSION AND SUMMARY

Many methods for estimating airblast from cased explosive charges employ the simplifying assumption that the inertial resistance of the casing (i.e., case mass-to-explosive mass ratio) is the dominant parameter. Recent experiments have suggested that casing material properties can be of importance in addition to the casing mass properties. In this paper, an experiment was devised and conducted to test the notion of casing inertial resistance being the dominant parameter for predicting airblast from cased charges.

To achieve this, a scored casing was designed which would have overall mass properties similar to medium-cased charges previously tested on the AFRL blastpad. The depth of scoring, however, produced regions where casing thickness was similar to that of lightly-cased charges previously tested on the AFRL blastpad. By comparing the measured airblast from the scored casing charge to these two existing data sets, insight could be gained regarding the parameters of greatest importance. One of these scored casing charges was tested on the AFRL blastpad in the summer of 2004. Approximately thirty-eight airblast pressure measurements were obtained at different distances and azimuths from the cased charge. A rudimentary effort at collecting and characterizing fragmentation from the scored casing was also performed.

The airblast waveforms from the scored casing experiment were compared to those from the three preceding lightly-cased charges and the three preceding medium-cased charges. Key airblast parameters were identified and tabulated from the measured waveforms, including shock time-of-arrival, peak pressure, and peak impulse. For the case of the lightly-cased and medium-cased charges having replicate experiments, the parameters were averaged to form a single set of airblast parameters for each charge type. Contour plots of time-of arrival, peak pressure, and peak impulse were generated for each charge type, and compared to one another.

These contour plots proved especially useful for spotting trends in the measured airblast environments. Observations included:

1. Time-of-arrivals from the scored casing more closely matched those of the lightly-cased charges.
2. Peak pressure environments more closely matched those of the medium-cased charges, although were slightly greater at most positions in the field.
3. Peak impulses off of the side of the scored casing more closely matched those of the lightly-cased charges.
4. Peak impulses off of the ends of the scored casing more closely matched those of the medium-cased charges.
5. The airblast environment from the scored casing charge was not perfectly consistent with either the lightly-cased or medium-cased charges; in fact, the scored casing was clearly an <u>“intermediate”</u> condition.

Given the intermediate airblast environments produced by the scored casing, it is concluded that both the inertial resistance and the casing expansion/fracture process are important physical processes influencing the airblast production from a cased explosive charge. Future efforts to devise improved methods for predicting airblast from cased charges might benefit from modeling both physical processes.

The effort to characterize fragmentation from the scored casing met with mixed success. Only one of the three break screens yielded useful fragment velocity data, and thus, fragment data is not included in this paper. It is intended to further refine the fragment characterization capabilities of the AFRL blastpad so that the highly detailed airblast characterization can be augmented by fragment characterization.

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